a method of forecasting returns from ponderosa pine dwarfmistletoe control

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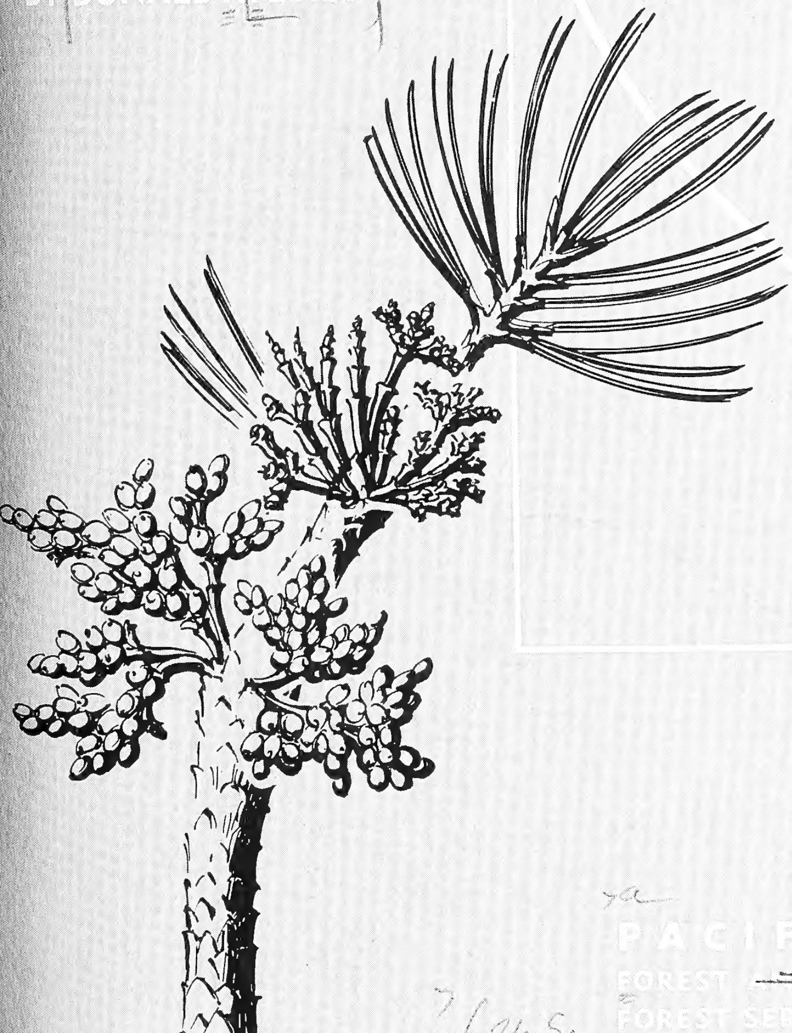

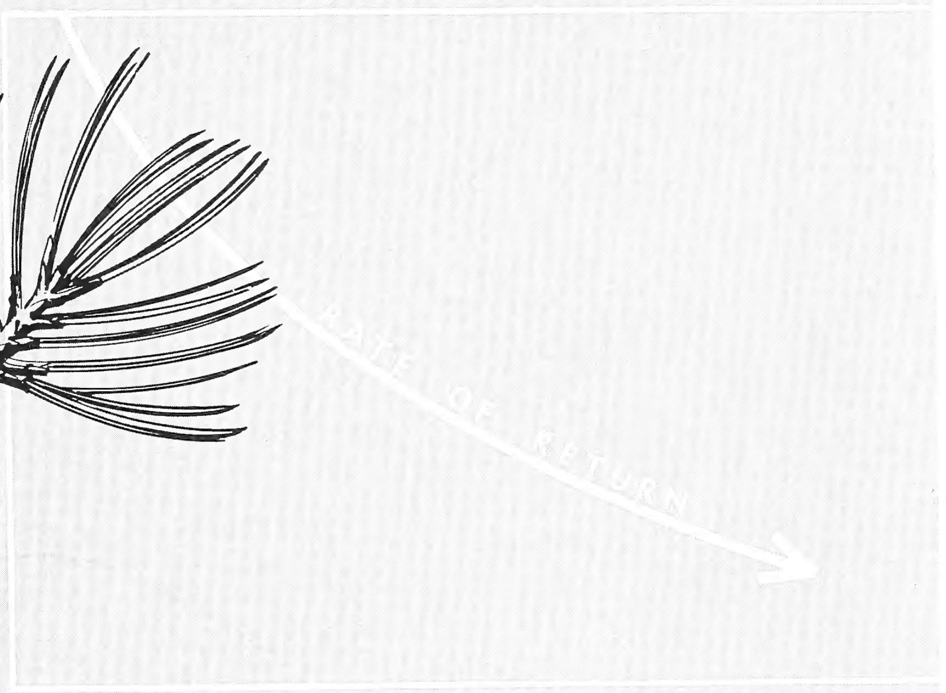

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SUMMARY

Procedures and data used in developing estimates of costs and rates of return for three methods of dwarfmistletoe control are explained in detail. Results of the calculations have already been published as "Economic Guides for Ponderosa Pine Dwarfmistletoe Control in Young Stands of the Pacific Northwest" (Flora 1966). This explanation of methodology is intended for persons particularly interested in the simulation models employed.

INTRODUCTION

BACKGROUND AND OBJECTIVE

Interest in dwarfmistletoes and their impact on timber production in the West is not new. Cooper in 1906, Woolsey in 1911, Meinecke in 1914, Weir in 1916, and Munger in 1917 reported on western dwarfmistletoes. A considerable history of biological research on the parasites has developed, and surveys have suggested the wide extent of dwarfmistletoe infestation (Hawksworth and Lusher 1956). In the 1950's, dwarfmistletoe control techniques became generally operational.

In 1959, the Pacific Northwest Forest and Range Experiment Station undertook a study of the economics of ponderosa pine dwarfmistletoe control. The specific questions asked were: How much does dwarfmistletoe control cost under different stand conditions? Can returns from control justify the cost? If yes, what stands should receive priority for treatment?

It was soon found that treatment cost data and information obtainable on growth of infected trees were based on measurements of single trees or stands. Systematic studies across representative ranges of infection, stand size, and density had not been made. Therefore, in 1961, treatment cost studies were made on the Deschutes National Forest in eastern Oregon. Arrangements were also made to obtain interim, tentative results from dwarfmistletoe studies planned or already started by the Divisions of Forest Disease Research at the Rocky Mountain and Pacific Northwest Forest and Range Experiment Stations. By 1964, it was

decided that sufficient information was available for varied combinations of stand characteristics to complete the economic study. The resulting publication was "Economic Guides for Ponderosa Pine Dwarfmistletoe Control in Young Stands of the Pacific Northwest."

This report explains in greater detail the cost data, growth information, economic values, and analytical procedure used in that publication.

THE ALTERNATIVES EXAMINED

Dwarfmistletoe control in juvenile stands is commonly accompanied by timber stand improvement measures, specifically pruning and thinning. However, this study dealt with mistletoe control alone, and the economics of silvicultural pruning are not considered here.

Precommercial thinning does enter the analysis, because precommercial thinning and dwarfmistletoe control are interdependent. That is, they are joint operations in that they occur simultaneously, one operation generally accomplishes part of the objective of the other, and costs incurred for one may reduce the cost of the other. For example, thinning usually removes some infected trees, and disease control eliminates some silviculturally undesirable stems. Interdependence of the two treatments may also be detrimental--disease control may reduce stocking below the silvicultural optimum.

Because of the relationship of thinning and disease control, four alternative treatment options were considered for infected stands:

1. Thinning only
2. Mistletoe control only
3. Mistletoe control with thinning
4. Mistletoe control in previously thinned stands

All of the options refer to juvenile stands, in which treatments are cost producing not income generating.

For each investment option, treatment cost per acre and rate of return on treatment investment were determined for several thousand combinations of stand characteristics. The following sections describe: first, hôw treatment costs were estimated; second, how returns from treatment were estimated and integrated with cost to establish profitability.

ESTIMATING TREATMENT COSTS

THE METHODS OF TREATMENT

Dwarfmistletoe control involved physical removal of infected branches or felling of infected trees. The procedure called for (1) removal of overstory trees as a part of the organization's timber harvest program; (2) thinning to remove understory trees with (a) stem infections, (b) limb infections close to the bole, or (c) so many branch infections as to make pruning impractical; and (3) pruning infected branches from the remaining trees. Thinning was done with powered circular saws called brush-cutters; pruning was with pole saws. Overstory trees of less than merchantable size were felled with chain saws.

The specific guidelines employed in the study were:

1. Work through the mistletoe area, removing all the smaller heavily infected trees, trees with severe stem infections, and large infected trees that are definitely not savable.

2. Rework the area, starting with the largest trees, selecting uninfected or infected prunable trees to leave. Decrease tree size classes until proper number of leave trees are found.

3. Remove all remaining infected or noninfected trees to the desired spacing.

. . . try to retain a minimum of at least 150 uninfected leave trees per acre in heavily infected stands.

When a definite hole 35 to 40 feet in diameter or larger occurs because there are no uninfected or prunable infected trees that can be left, or when spacing begins to exceed an average of 16 feet, trees of 2 inches d.b.h. or over and having not more than two infections in the lower one-third of the bole may be left, provided there are no uninfected 1-inch d.b.h. class or smaller leave trees within 25 feet.

Cut all infected but vigorous crop trees, even if only one or two mistletoe infections occur above prunable height. However, if cutting a tree leaves a nonstocked

opening, the tree can be left if plans are made to remove the infected branch by other than normal pruning procedures. In this study, it will be considered better to leave a small, nonstocked opening than to leave a tree with infection high in the crown.

Thin and prune to remove all visible mistletoe infection. Retain about 50 percent more than normal stocking if possible. (For example, if normal stocking for site IV[1] is 355 leave trees per acre at an average spacing of 11 feet by 11 feet, 50 percent more would bring the number of leave trees per acre up to 533 at 9 feet by 9 feet average spacing.) This will provide for subsequent rethinning at periodic intervals, or until mistletoe is controlled.

Remove all trees with infections in, or within 4 inches of, the bole and all trees from which infection cannot feasibly be pruned (normally above 20 feet). Thin and prune uninfected portions of the stand according to normal procedures and stocking.[2]

The guidelines were prepared by National Forest staff personnel to conform to general field practice in the Northwest.

It was also necessary to estimate the cost of precommercial thinning without attention to dwarfmistletoe control. Precommercial thinning was also done with brushcutters, using a crop-tree, rather than a uniform, thinning philosophy. Crop-tree thinning emphasizes selection of desirable dominants or codominants for leave trees, sacrificing uniformity of spacing if necessary.

A stocking objective of 355 stems per acre was employed for precommercial thinning. In infected stands, 50 percent more stems were left to allow for stocking reduction in subsequent recleanings.

DATA COLLECTION

Field research on treatment costs was based on time studies of experienced crews. Seventy-seven compartments, averaging 2 acres in size, were established in infected stands on the Deschutes National Forest. An additional 12 compartments were placed in uninfected stands. Stand characteristics were measured with a grid of 1/250-acre plots spaced 1 chain apart. A broad range of stand characteristics was involved:

Average d.b.h., 1 to 4 inches
Stems per acre, 400 to 10,000
Percent of stems infected, 0 to 92

Stopwatch studies were made under generally favorable weather conditions. Work was suspended in cloudy weather because of difficulty in seeing mistletoe plants at such times. As in operational work, string lines were run at 2-chain intervals to guide the crewmen. Two men, accompanied by a timekeeper, worked in each 2-chain-wide strip. As in normal practice, 2 foremen and a saw maintenance man were employed for each 10-man crew. For each crew, two "carry-

[1] U.S. Forest Service. National Forest timber stand improvement handbook, Region 6. 1963.

[2] Dykeman, K., and Simonson, J. Project work plan for study of dwarfmistletoe control costs. 12 pp. 1961. (On file at Deschutes National Forest, U.S. Forest Service, Bend, Oregon.)

all'' enclosed vehicles and a pickup were generally used. Fifteen thinning saws were kept available for a 10-man crew to minimize breakdown delays. When pruning infected trees, each man had one 7-foot and one 14-foot pruning saw.

Delay and work times were subdivided according to the activities from which they arose. Timekeepers recorded the effort devoted to each compartment to the nearest man-minute.

DWARFMISTLETOE CONTROL WITH THINNING

Regression analysis was used to relate the per-acre time and cost of treatment to stand characteristics. Dwarfmistletoe control with precommercial thinning requires separate felling and pruning operations.

Felling.--An equation for predicting man-hour requirements for the felling portion of treatment was based on 77 compartments:

$$\text{Man-hours per acre} = 1 + 0.00133DS$$

$$R \text{ (correlation coefficient)} = 0.95$$

where D is average d.b.h. before treatment, and S is stems per acre before treatment.

Reduction of residual variance attributable to addition of a variable measuring the level of dwarfmistletoe infection was nonsignificant at the 5-percent confidence level. The relative unimportance of the infection variable (after stand density and tree size are used) can perhaps be attributed to the fact that once the stand is known to be infected, each tree must be searched visually for mistletoe plants. Scanning time is probably directly related to tree size and the number of trees per acre. Both of these factors are already in the equation. The influence of infection intensity on felling time per acre may be slight, at least in stands whose density is such that at least as many trees as are infected must be cut anyway for silvicultural reasons.

Pruning.--For pruning, the comparable equation is:

$$\text{Man-hours per acre} = 2.58 + 0.01495DM$$

$$R = 0.97$$

where M is number of stems pruned per acre.

Experience on the infected compartments led to an equation for predicting the number of stems pruned per acre for mistletoe:

$$\text{Stems pruned per acre} = 25 + 0.0746I - 0.0000125I^2$$

$$R = 0.76$$

where I is the total number of stems per acre that are infected before treatment.

DWARFMISTLETOE CONTROL ONLY

For dwarfmistletoe control without precommercial thinning, pruning operations require as much effort as for control with precommercial thinning; hence, there is no change in the man-hour equation for pruning. However, a revised felling equation is necessary because only infected trees are felled. An estimate of time saved by leaving uninfected stems was obtained from an equation developed for thinning uninfected stands, whose derivation is described elsewhere

(Flora 1966). The latter equation is:

$$\text{Man-hours per acre} = -0.183 + 0.000203S + 0.000569SD$$

where S = total stems per acre before treatment; D = average d.b.h. before treatment. The derivative of this equation with respect to S gives an estimate of work time per uninfected tree. Thus, the derivative $(0.000203 + 0.000569D)$, multiplied by the difference between total stems and infected stems per acre, can be subtracted from the man-hour equation for control with precommercial thinning to obtain an equation for control without precommercial thinning. The resulting equation, using the previous notation and letting I = number of infected stems per acre, is:

$$\text{Man-hours per acre} = 1 - 0.000203S + 0.000203I + 0.00076SD + 0.00057DI$$

All of the man-hour equations include an upward adjustment for operational delays such as fueling and breakdowns. It was found that, on the average, an additional 30 percent of work time must be added for delay time in thinning operations and 18 percent in pruning operations.

UNIT COSTS AND COST EQUATIONS

Each of the foregoing man-hours-per-acre equations has a companion cost-per-acre equation. An average hourly labor cost of \$2.38 was used, based on actual crew costs including FICA charges, payroll overhead, and field supervision. The powered thinning saws cost about 93 cents per machine-hour for maintenance, repair, replacement, and fuel. Pruning saws cost about 6 cents per man-hour of use.

The cost-per-acre equations are:

Dwarfmistletoe control with precommercial thinning--

$$\text{Thinning portion, \$/acre} = 5.21 + 0.00608DS$$

$$\text{Pruning portion, \$/acre} = 8.90 + 0.0497DM$$

where M is stems pruned per acre.

Dwarfmistletoe control without precommercial thinning--

$$\text{Thinning portion, \$/acre} = 5.28 - 0.000912S + 0.000912I + 0.002212DS + 0.00260DI$$

$$\text{Pruning portion, \$/acre} = 8.90 + 0.0497DM$$

TRAVEL COST

Of costs that cannot be attributed directly to crewmen's efforts, travel is the largest. Travel cost includes both vehicle and labor costs while crewmen travel on "company" time. A table of adjustment factors for travel cost was prepared (table 1), using a vehicle cost of 15 cents per mile for each of two vehicles assigned to a 10-man crew. A third vehicle was included in overhead supervision cost.

Table 1 assumes that crewmen travel in one direction, to or from the job, on their personal time but that vehicle costs in both directions are charged to the project.

Table 1.--Factors for adjusting dwarfmistletoe control costs to include travel cost[1]

Travel time during an 8-hour shift (minutes)	Distance, round trip, miles							
	10	20	30	40	50	60	70	80
15	1.052	1.071	--	--	--	--	--	--
30	1.088	1.109	1.129	1.150	--	--	--	--
45	1.125	1.148	1.170	1.192	1.214	1.236	--	--
60	--	1.191	1.215	1.239	1.262	1.286	1.310	1.334
75	--	--	1.262	1.288	1.314	1.339	1.365	1.391
90	--	--	--	1.342	1.370	1.397	1.425	1.453

[1]Multiply estimated cost without travel by the appropriate adjustment factor. A vehicle and labor cost of 15 cents per mile is assumed.

ESTIMATING TREATMENT PROFITABILITY

Treatment cost per acre alone is not adequate for giving stands priorities for improvement work, because treatments of equal cost on different stands may produce different value-growth response. Thus, it is necessary to forecast growth and value yield attributable to treatment and relate these to treatment cost in terms of rate of return on investment. These elements--yield with and without treatment and calculation of rate of return--are described below.

BEHAVIOR OF DWARFMISTLETOE-INFECTED STANDS

Investigations by T. W. Childs and James Edgren of the Pacific Northwest Forest and Range Experiment Station are the basis of this section. The relationships employed here are tentative and as yet unpublished.

Over a period of several years, they made detailed measurements of 2,097 trees on plots within the Winema (formerly portions of the Deschutes and Fremont) National Forest in eastern Oregon. Their data were used to relate d.b.h. (in the absence of treatment) to various silvicultural and pathologic factors:

$$\begin{aligned} D = {} & 110.25 - 35.97Q + 0.119A \\ & + 0.024G + 4.147Q^2 - 0.129G^2 \\ & - 0.028QA + 0.109QG + 0.001AG \\ & - 85.07\,(\mathrm{Log}\,Q) + 36.49\,(\mathrm{Log}\,A) \\ & - 196.6/Q + 507.4/A \end{aligned}$$

where Q is site class,[3] A is age, G is infection class,[4] and R (correlation coefficient) = 0.69.

All the coefficients of this lengthy equation are significant at the 95-percent level.

[3]Meyer's site classes (1938) were used.

[4]Infection level is classified according to a rating system described in U.S. Dep. Agr. Tech. Bull. 1246, p. 77 (Hawksworth 1961). 0 represents no infection and 6.0 indicates maximum severity.

Equations for predicting total tree height were based on the same data source and were developed separately for different levels of attained infection:

Infection classes	Equation	R	N
1-2	$H = 93.28 \text{ Log } (D-3.0) - 15.4$	0.92	176
3-4	$H = 81.22 \text{ Log } (D-4.0) + 0.9$	0.93	99
5-6	$H = 82.40 \text{ Log } (D-3.0) - 10.2$	0.88	93

where H is total height, D is d.b.h., and N is number of observations.

Covariance analysis showed these equations give significantly different estimates at the 95-percent level.

From the above-mentioned height and diameter estimates, individual tree volumes can be estimated from an appropriate volume table. For this purpose, an equation was derived from a Scribner volume table developed by Meyer (1938, table 34). The equation is:

$$V/D = 0.53 - 0.276D - 0.094H + 0.0179DH$$

where $\bar{V}$ is board-foot volume, Scribner rule, D is d.b.h., and H is total height in feet.

R for this equation is 0.9996; however, it should be noted that in this case, where data are based on curves, R has meaning only as a measure of closeness of fit.

The effect of dwarfmistletoe on stocking is much more difficult to estimate. On the basis of Childs' findings in eastern Oregon, ratios were obtained relating periodic mortality in infected stands of various infection levels to periodic mortality in otherwise comparable but uninfected stands. The ratios were placed in continuous form by the function:

$$\text{Log ratio} = -0.13653 + 0.20841G$$

where G is average infection class.

It was necessary to relate infection class to tenure of infection. Field observations suggest that, in the Northwest, average infection class moves from about 1.5 to about 5.5 in approximately 70 years. Transect studies in Colorado[5] showed infection class to be linearly related to time infected. If it is assumed that linearity holds in the Northwest as well, it follows that

$$G = 0.06T$$

where G is average infection class and T is number of years infected.[6]

In Colorado, it was also observed that

$$G = \frac{3P}{450 - 4P}$$

where G is average infection class within a plot and P is percentage of trees infected (expressed as a whole number). Acceptance of this observation for the Northwest seemed reasonable.

BEHAVIOR OF UNINFECTED STANDS

The above-mentioned mortality ratio requires a stocking estimate against which to apply the ratio. Lynch (1958)

[5]Results of this work, conducted by Hawksworth of the Rocky Mountain Forest & Range Experiment Station, have not been published. Similar work on lodgepole pine has been reported (Hawksworth and Hinds 1964).

[6]The comparable relationship found by Hawksworth is $G=0.08T$.

used data collected in the Inland Empire to devise equations for predicting stocking trends in natural, unthinned, and uninfected stands:

$$W = b\left[0.5663 - 0.2715(h/a) + 15.2858(1/a)\right]$$

$$\text{Log } Z = 2 + (\text{Log } W - 2)(a/a^*)$$

$$E = 0.5663 - 0.2715(H/a^*) + 15.2858(1/a^*)$$

$$B = Z/E$$

$$\text{Log } S' = -2.6078 \text{Log } H - 11.215(1/a^*) + 1.4579 \text{Log } B + 4.1007$$

where W, Z, E = stocking factors used in the subsequent function,

- b = basal area per acre at some initial age a (square feet),
- B = basal area per acre at a subsequent age a^* (square feet),
- S' = number of stems per acre at age a^*,
- h = average height (feet) of dominant trees at age a, and
- H = average height (feet) of dominant trees at age a^*.

Values for h, H, and the constant, 4.1007, were based on Meyer's yield table (1938).

Introduction of two more functions, one to predict total height of the average tree[7] and the other to compute volume per tree, permits determination of merchantable volume per acre. The latter has been described earlier. The former is:

$$H' = -25 + 4.29D - 0.0595D^2 + 0.414Q' + 0.00186A^2 + 0.00672DA$$

where H' = total height (feet) of average tree, Q' = site index, and other notation is as before. This function was fitted to height curves in Meyer's yield table (1938, *p. 48*). Its high correlation coefficient of 0.986 indicates closeness of fit, not statistical reliability.

[7]This height function is for uninfected trees only; the height formulas given earlier are only for infected trees.

STAND PROJECTIONS

The foregoing growth relationships were employed together to forecast or simulate the growth of numerous hypothetical, but representative, timber stands varying as to dwarfmistletoe infection intensity at time of treatment (if any); stand age, stocking, and average d.b.h. at time of treatment; and site quality. Yield predictions were made for each of six stand conditions:

1. No dwarfmistletoe, no silvicultural thinning
2. Dwarfmistletoe infection, no control, no silvicultural thinning
3. Dwarfmistletoe control without silvicultural thinning
4. No dwarfmistletoe, silvicultural thinning
5. Dwarfmistletoe infection, no control, silvicultural thinning
6. Dwarfmistletoe control with silvicultural thinning

STAND PROJECTIONS-- NO SILVICULTURAL THINNING

No dwarfmistletoe.--Suppose, for example, we have a 1-acre 30-year-old stand on site IV, with an average d.b.h. of 2 inches and 4,000 stems per acre. It is assumed that the tree of average basal area is also 2 inches in diameter, so that basal area per acre at age 30 is 2^2 X 0.005454 X 2,000 = 87 square feet. Assume, further, an average height of dominants of 30 feet. If this stand is uninfected, the functions above support a prediction that 90 years later at age 120, there will be about 173 square feet of basal area and 168 stems per acre. Thus, basal area per tree would be 1.03 square feet, suggesting an average d.b.h. of about 13.5 inches. Volume per acre would be about 23,500 board feet.

Dwarfmistletoe infection, no control. --If this stand has been infected with dwarfmistletoe with, say, an average infection class of 1.0 at age 30, it would be possible to follow growth on a hypothetical basis. At age 40, average d.b.h. would be 4.2 inches, and there would be about 400 stems per acre. If no sanitation or other stand improvement measures were undertaken in the interim, by age 120 average infection class would increase to almost 6, and there would be only a few trees per acre, of low merchantability, with an average d.b.h. of about 12 inches. During the 80-year interval, infection would also have spread outward, causing growth reduction and increasing mortality in adjacent stands. The amount of impact depends on length of time infected and thus on distance from initial infection zone, with the more distant trees affected least. Because of this varying impact across the invaded area, average impact per acre is difficult to compute. Average impact can be approximated by computing average time infected, assuming a circular initial infection zone and a constant rate of spread in all directions. In the example above, average time infected in the area invaded during the rotation would be 47 years,[8] although time infected in the initial source acre would be about 102 years.

Dwarfmistletoe control.--If control of dwarfmistletoe were undertaken at age 30, without concurrent silvicultural thinning but with followup recleanings, it can be assumed that the sanitized stand would behave growthwise like a similar but uninfected stand. However, fewer stems would remain per acre, and their average d.b.h. would tend to be smaller, because dwarfmistletoe is more apt to be found on dominants than on smaller trees. Assume that sanitation causes a 25-percent reduction in average d.b.h., as occurred on the time-study areas, and that the number of trees felled is close to the number of infected trees observed during precleaning reconnaissance. Then, in the example, volume per acre at rotation age would be about 20,000 board feet, with d.b.h. averaging about 15 inches.

STAND PROJECTIONS-- SILVICULTURAL THINNING ASSUMED

Thus far, three alternative stand conditions have been discussed, none

[8]It can be shown that mean time infected is

$$\frac{1.64K - 1.35L - 2.69TL + 1.79L^2}{3.28 + 2.69L}$$

where $K = \sqrt{43{,}560U/\pi}$

U = area of initial infection zone in acres,

T = time (years) initial infection zone has been infected,

L = time span (years) during which infection extends beyond initial infection zone.

involving silvicultural stand improvement; e.g., precommercial thinning. The three conditions were: no dwarfmistletoe infection, infection without control, and infection followed by control. The same three conditions could also be found in a stand receiving precommercial thinning.

No dwarfmistletoe.--To help forecast yields under these conditions, basic yield estimates for uninfected, thinned stands have been developed by the Forest Service.[9] Because some of the estimates were prepared specifically for this study, relevant portions are listed in table 2. The yield forecasts assume that stocking will be reduced by thinning to the levels

[9]U.S. Forest Service. National Forest timber stand improvement handbook, Region 6. 1963.

Table 2.--Abstract of assumed thinning schedules and yield estimates for uninfected ponderosa pine (Basis: 1 acre)

Site class	Average growth rate	Age class	Cut			Leave		
			Average d.b.h.	Stems[1]	Volume	Average d.b.h.	Stems[1]	Volume
	Rings per inch	Years	Inches	Number	M bd. ft.	Inches	Number	M bd.ft.
II	8	Up to 40	--	--	--	2-5	435	--
		60	7	145	--	10	290	5
		80	11	120	9-1/2	15	130	23-1/2
		100	18	130	49	--	--	--
III	10	Up to 40	--	--	--	2-6	435	--
		60	7	165	--	10	275	--
		80	11	145	9	14	130	16
		100	17	130	27	--	--	--
IV	12	Up to 40	--	--	--	2-5	355	--
		60	--	--	--	8	355	--
		80	9	175	--	12	180	9
		100	13	85	9	15	95	13
		120	16	95	23	--	--	--

[1]For convenience here, estimated mortality is included with cut.

indicated for age class 40. These levels have become standard on National Forests in the Pacific Northwest.

Dwarfmistletoe infection, no control. --Yield predictions for infected stands thinned without regard for dwarfmistletoe, or for stands infected after thinning, may seem irrelevant since standard field practice involves sanitation and silvicultural thinning simultaneously. However, it is not impossible that thinning might be economic in infected stands where the considerable additional effort of sanitation may not be worth while. In any case, some infected stands are in fact thinned without dwarfmistletoe control. Further, separation of the two functions for economic analysis can aid in attributing costs separately to stand improvement and pest control budgets.

In the hypothetical stand discussed above, thinned and mistletoe-infected, diameter estimates for uninfected stands must be adjusted downward. This was done by applying a ratio of mean d.b.h. in infected v. uninfected stands, based on the Childs-Edgren diameter relation cited earlier. A similar, varying adjustment was applied to volume yields. It is assumed that dwarfmistletoe-caused mortality would be captured; hence, no stocking impact would be involved. For the example, thinning yield available at age 120 would be about 4,400 board feet instead of 23,000, as shown in the table for site IV.

Dwarfmistletoe control.--Yield forecasts can also be made for thinned stands that are concurrently treated for dwarfmistletoe. Because sanitation affects residual mean diameter and volume, table 2 values were arbitrarily reduced 15 and 25 percent, respectively.

TREATMENT OPTIONS

The six stand-condition simulations permit economic evaluation of the four stand-treatment options listed in the "Introduction." The economic advantage of each option depends on comparing the treatment cost and value yield of two stand conditions. For example, the benefit from thinning with dwarfmistletoe control is the difference in value yield of a treated stand and an infected stand without treatment. The four options and the stand-condition yields compared, all involving infected stands, are:

This option[10]	Compares this condition	With this
Silvicultural thinning only	Thinned, no sanitation	Unthinned, no sanitation
Sanitation only	Sanitation, unthinned	Unthinned, no sanitation
Sanitation with thinning	Thinned, sanitation	Unthinned, no sanitation
Sanitation after thinning	Thinned, sanitation	Thinned, no sanitation

RATES OF RETURN ON INVESTMENT

Each of the four investment options was evaluated in terms of rate of return on investment for up to 2,000 combinations of various stand characteristics. Treatment cost has been discussed; the pruning-felling method of control was

[10] "Thinning" means silvicultural thinning as distinct from felling for sanitation reasons.

assumed for dwarfmistletoe control options because of the prevalence of this method in the Northwest. Returns from treatment are the value yields discussed in the preceding section. An average stumpage value of $15 per thousand board feet was assumed. This value is, of course, arbitrary and subject to variation from place to place. Stumpage price experience in the past and the national outlook for timber supply and demand (U.S. Forest Service 1965) were weighed in choosing this figure.

Calculations of rate of return on investment were oriented to holdings on which annual cutting plans are influenced by long-term growth and mortality forecasts. Most common methods of allowable cut calculation are of this sort. Thus, if it is expected that a dwarfmistletoe control operation will forestall a given annual mortality loss, the amount of growth saved by the operation can be credited to the allowable cut immediately, even if the treated stand is not merchantable itself. Of course, there must be sufficient merchantable timber elsewhere within the management unit in order for the increase in allowable cut to be realized. Such is generally the case on industrial and public forests in the Pacific Northwest.

Returning to the hypothetical stand used earlier, suppose that dwarfmistletoe control without silvicultural thinning is contemplated. The effect of treatment is to increase ultimate harvest yield by almost 20,000 board feet per acre, or 222 board feet per acre per year during the balance of the current rotation. If it is assumed that this increase will be reflected in the allowable cut, with additional trees harvested from merchantable stands having a net stumpage value of $15 per thousand, the rate of return on treatment investment can be found by finding p in the following annuity formula:

$$\frac{C}{a} = \frac{(1+p)^n - 1}{p(1+p)^n}$$

where C = treatment cost per acre ($42 per acre)[11]

a = mean annual value yield per acre per year ($15 x 0.222 = $3.33)

n = number of years remaining in the rotation (120 - 30 = 90)

p = rate of return on investment

In the example, p is found to be about 0.08, or 8 percent. Thus, in this stand (ignoring for simplicity the benefits arising from protection of adjacent uninfected areas), dwarfmistletoe control without other treatment can be expected to return 8 percent on the control investment.

Similar calculations were made for each treatment option for many different combinations of stand characteristics. Some stand attributes were found not to influence investment profitability significantly. Surprisingly, degree of dwarfmistletoe infection was one of these. Apparently, the slight importance of infection level arises from the large proportion of control time devoted to visual search for dwarfmistletoe plants relative to actual felling or pruning time. In an infected stand, every tree must be searched whether infected or not.

PRESENTATION FORMAT

For the stand characteristics that do aid in predicting rate of return, the effect of variation in any single stand

[11] From Flora (1966), figures 5 and 6.

attribute is apt to be in a regular pattern. Thus, if several stands differing only in, say, stocking, are treated, and if their densities are 1,000, 2,000, 3,000, and 4,000 stems per acre, rates of return on treatment costs might be 4, 6, 8, and 9 percent, respectively, varying always in the same direction. Erratic values like 4, 6, 3, 5, moving up, down, up, respectively, do not occur. Because of such regularity, it is easy to portray rates of return graphically, just as was done with treatment costs. Many columns of numbers can be conveniently presented on a single graph, and interpolation is made simpler.

To facilitate graphing, equations were fitted to relate rate of return to stand characteristics. Of the four treatment options listed earlier, it was found that the first, silvicultural thinning of dwarfmistletoe-infected stands without concurrent control measures, is not economic. That is, no set of stand characteristics was found for which the rate of return on treatment investment approached 3 percent, the rate considered here to be the minimum return acceptable to forest managers. Equations for the other three options, all involving young dwarfmistletoe-infected stands, are:

Dwarfmistletoe control without silvicultural thinning:

$$p = 11.35 + 0.0313Q' - 0.0008S - 0.2287A + 8.3649(1/A) + 1.1446D + 0.8553(1/D) - 0.1834U + 3.1677(1/U) - 0.0071DU$$

Dwarfmistletoe control with silvicultural thinning:

$$p = 16.91 - 0.0505Q' - 0.9557D - 0.0016S + 1820(1/S) - 0.2068U$$

Control after commitment to silvicultural thinning:

$$p = 21.0 - 0.2000Q' - 0.049A - 0.0305D^2 - 0.0002DS$$

where p = rate of return on investment (percent)

Q' = site index

S = stocking before treatment (stems per acre)

A = stand age

D = mean d.b.h. before treatment

U = size of infected area (acres)

SENSITIVITY TO LABOR COSTS

Since most of the cost of stand treatment goes to labor, a change in prevailing wage rates can affect rates of return on treatment investments. Costs in this analysis are based on hourly wage rates of about \$2.05 for crewmen and a salary of about \$5,000 per year for foremen. An additional allowance was added for payroll overhead--employer's contribution to FICA, health, and retirement plans. An average cost per man-hour, including payroll overhead and supervision, of \$2.38 was assumed.

In general, rate of return on treatment investment is inversely proportional to cost. Thus, if labor cost per hour increased to six-fifths of its former level, percent rate of return would become five-sixths of its previous figure.

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Simulation models for estimating rates of return on ponderosa pine dwarfmistletoe control investments are explained. Three control methods and four management philosophies are considered for holdings on which anticipated future yields influence current "allowable" annual harvest. Stand treatment priorities based on this work are in "Economic guides for ponderosa pine dwarfmistletoe control in young stands of the Pacific Northwest," U. S. Forest Service Research Paper PNW-29, 1966.

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